Line-Driven Wind in AGN from Full Hydro-Radiation-Ionization Simulations

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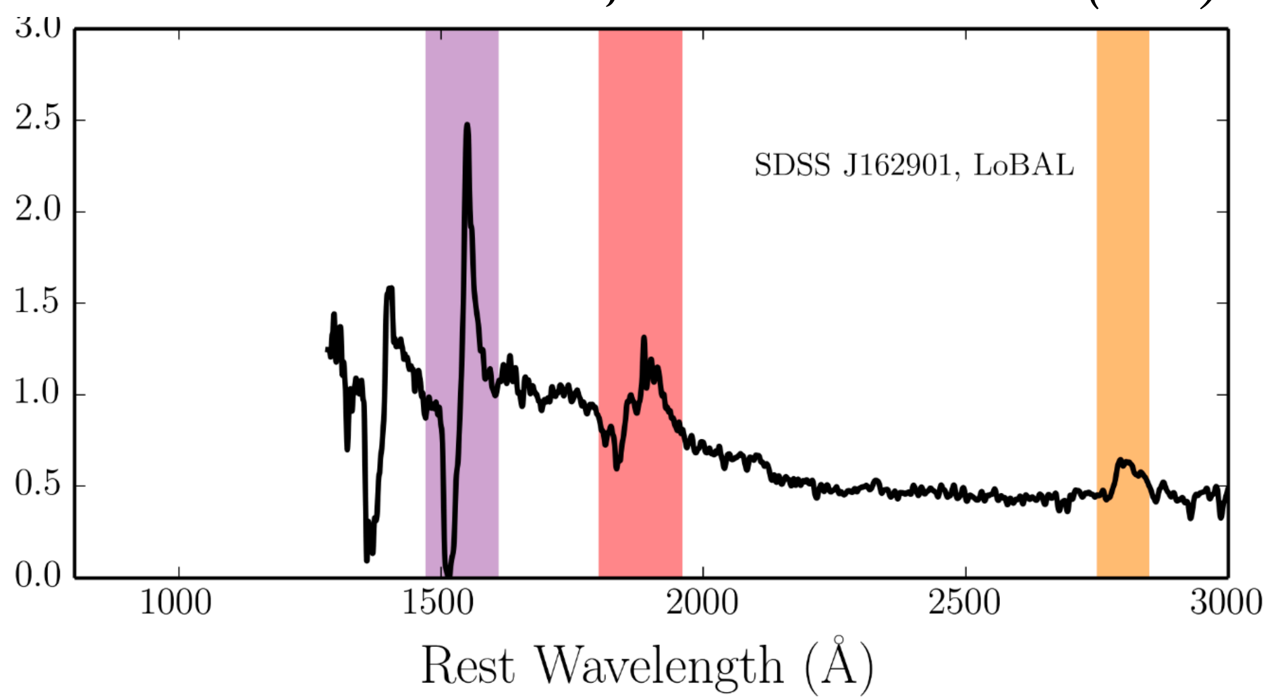
Winds in AGN

J. Matthews PhD thesis (2016)



Wind with terminal speed from ~0.01 c to ~0.3 c

(Korista et al. 1993, Trump et al. 2006, Tombesi et al. 2013)

$$\dot{M}_W \approx \dot{M}_{\mathrm{acc}}$$

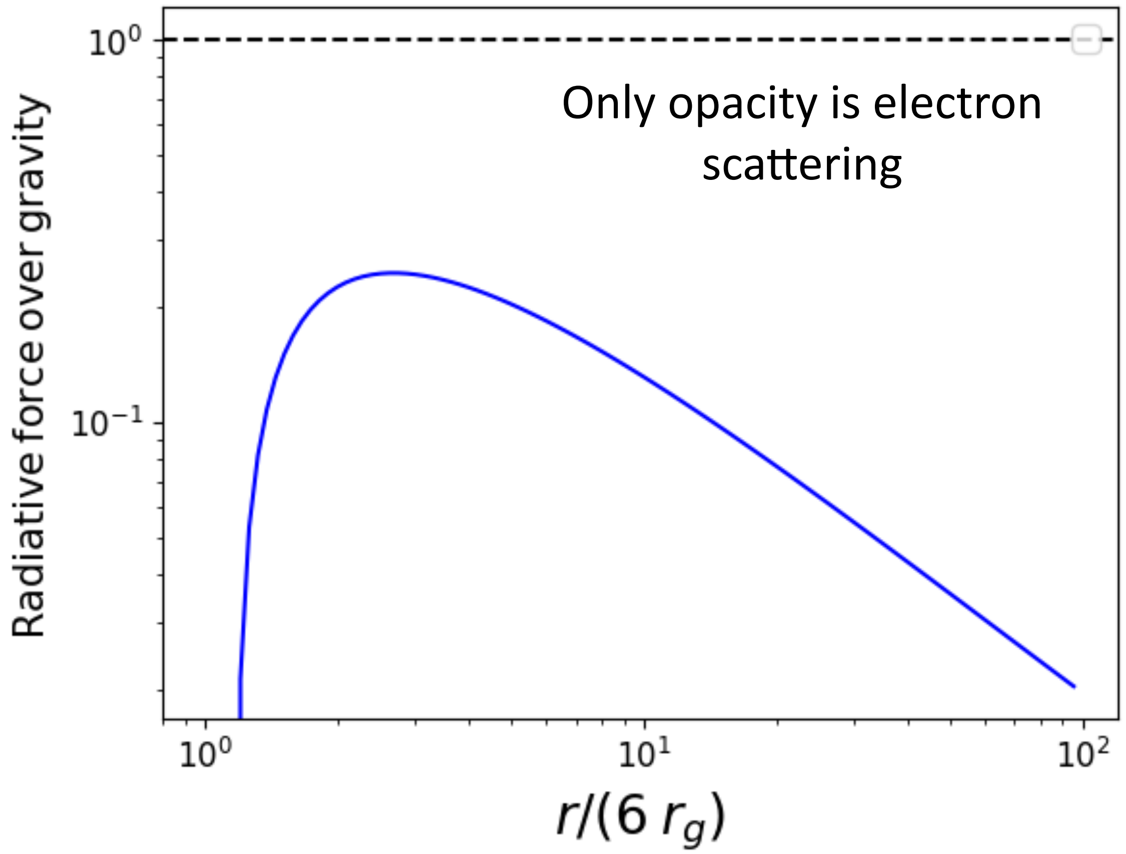
(Higginbottom et al. 2013)

Very powerful wind that can affect galaxy evolution !

How are AGN winds launched ?

Main candidate is radiative wind, where radiation pressure overcome gravity

AGN accreting at 0.4 Eddington



Need a factor of ~10 in AGN to drive a wind!

Need extra opacity to increase radiation-matter coupling

Line-driven winds and the over-ionization problem

Radiative force enhanced due to hundred thousands of atomic lines

Depend crucially on ionisation state of the wind.
(Extremely complicated to capture photo-ionization in simulations…)

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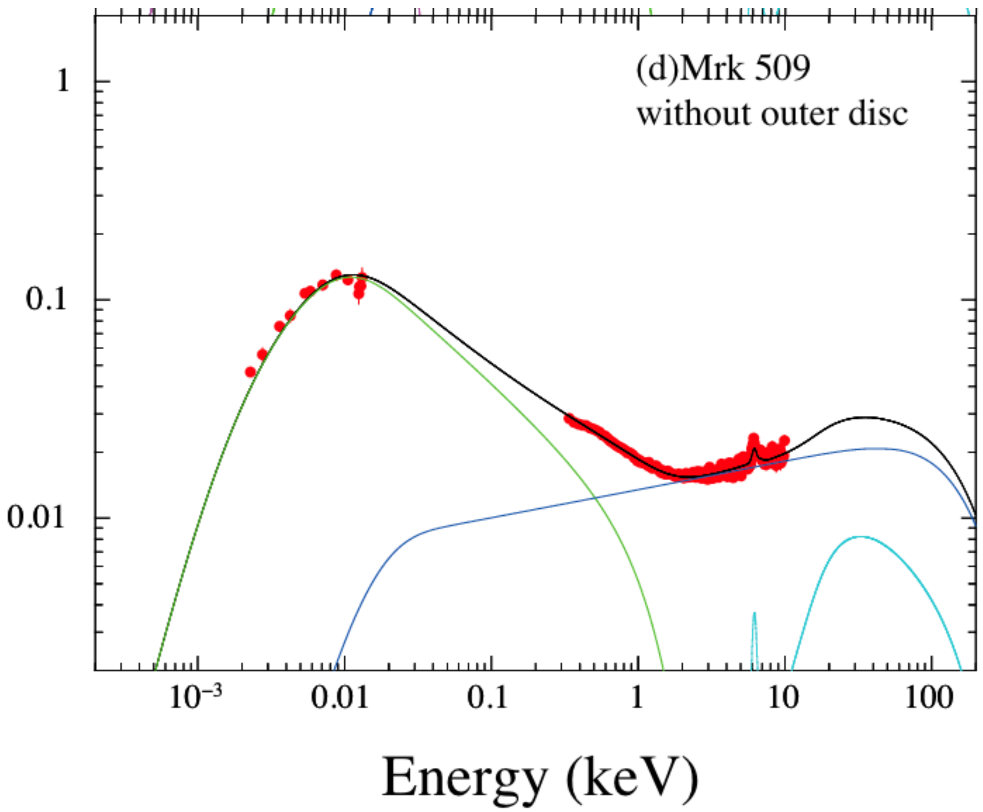
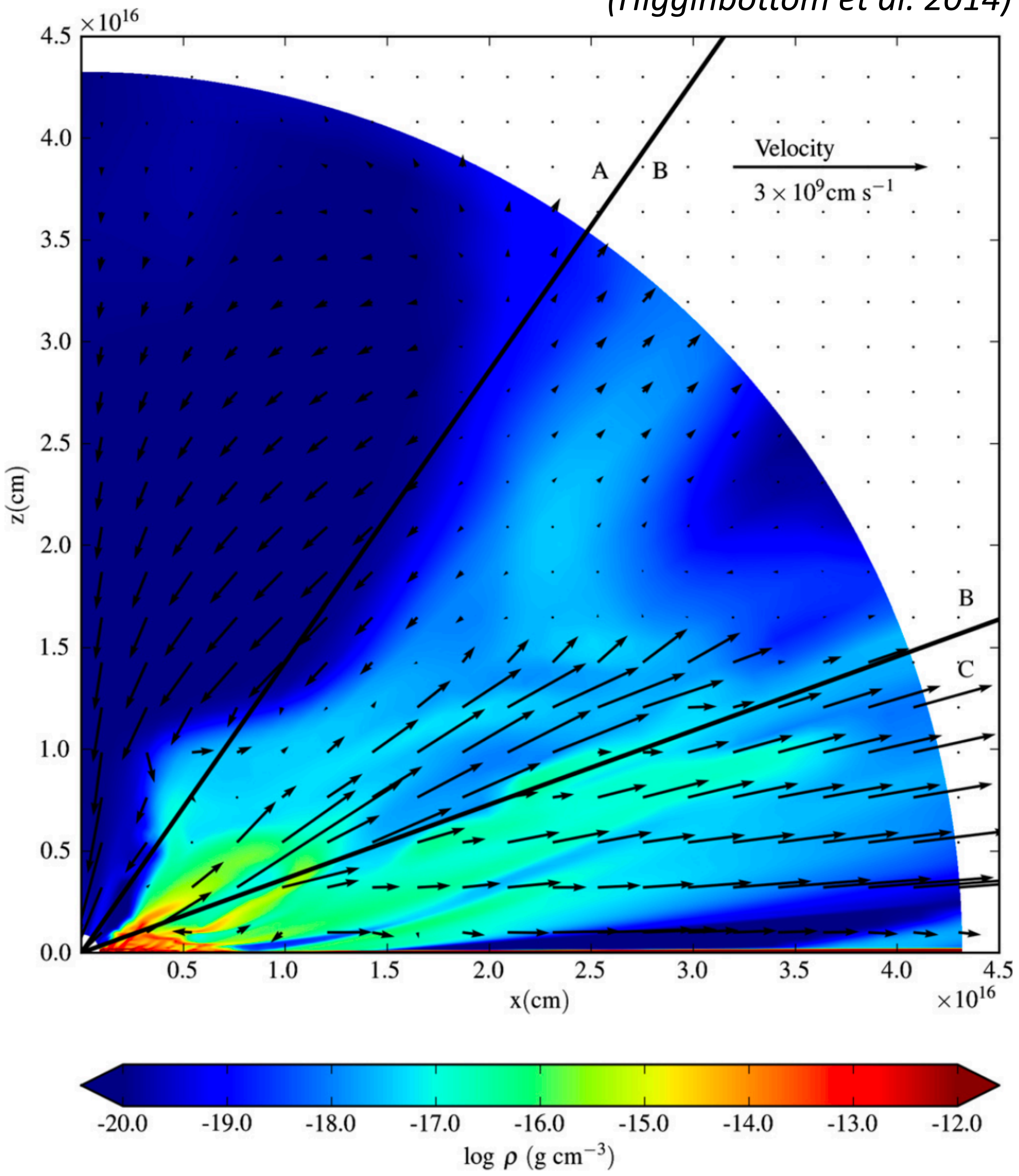


But AGN have strong X-ray emission that can make all lines disappear !

X-ray shielding

(Higginbottom et al. 2014)



Failed inner wind shields the outer wind from the X-rays

(Proga & Kallman 2004)

Strong steady-state wind with $\dot{M}_W \approx 0.25\dot{M}_{\rm acc}$

X-ray shielding

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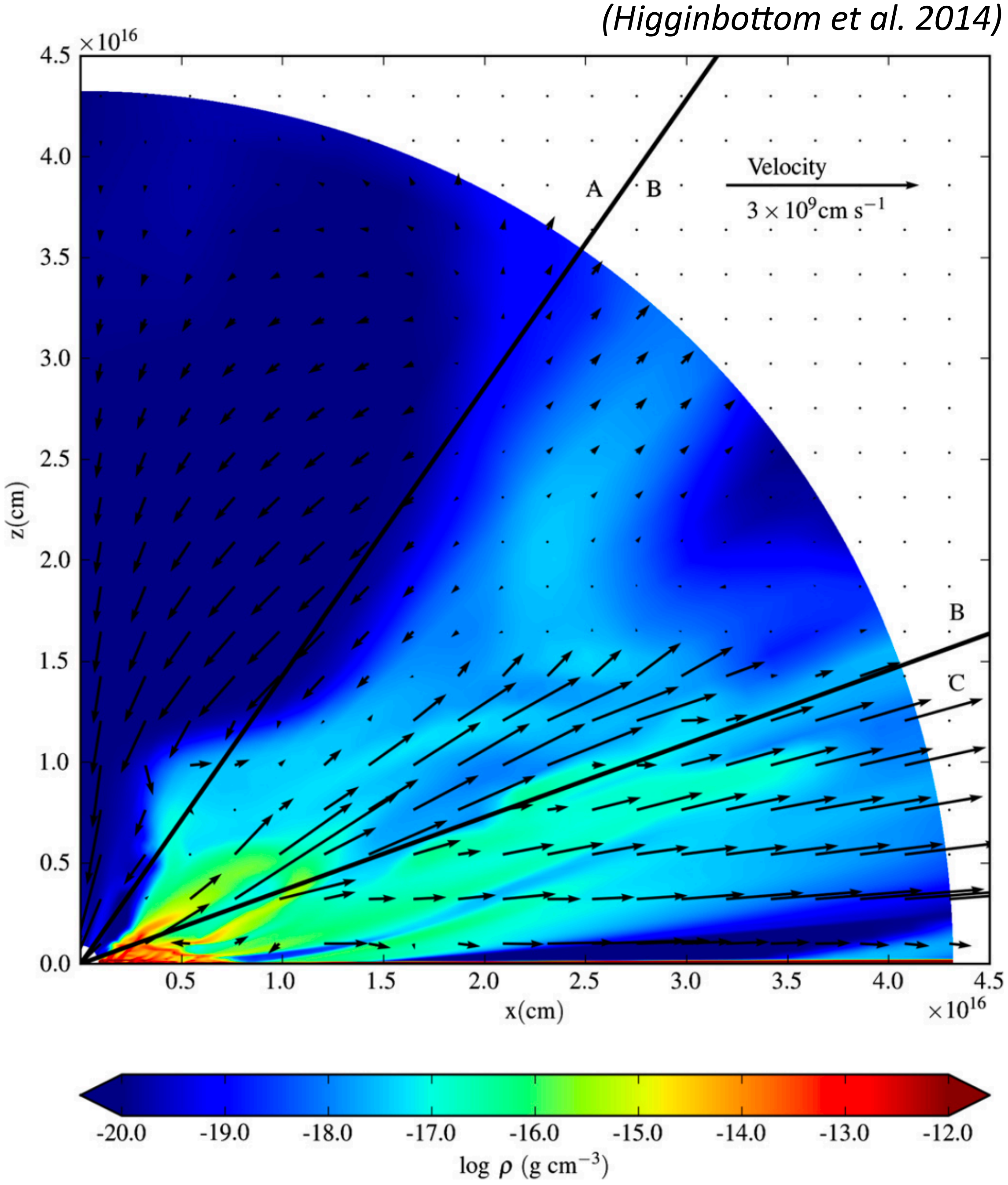


Failed inner wind shields the outer wind from the X-rays

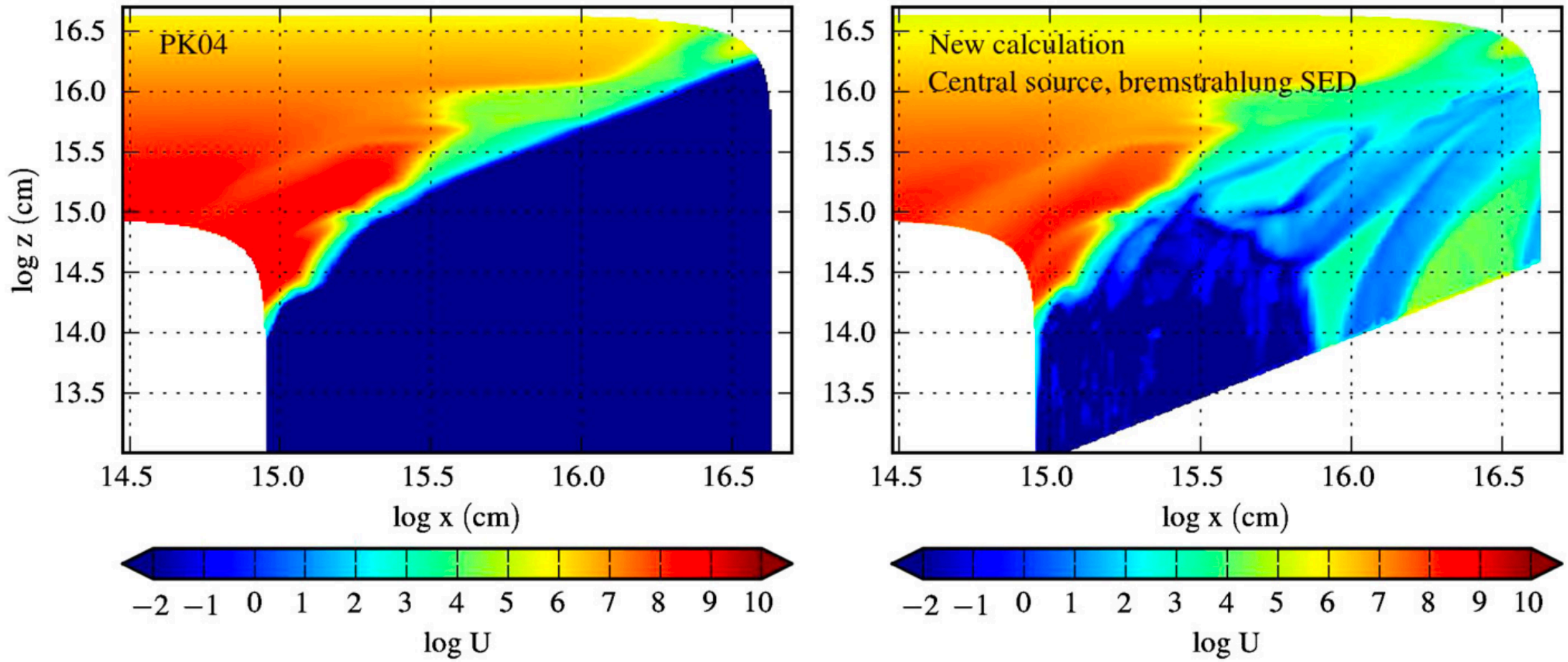
(Proga & Kallman 2004)

Strong steady-state wind with $\dot{M}_W \approx 0.25\dot{M}_{\rm acc}$

But simulation is too simple because:

- X-rays are absorbed but not scattered or reprocessed
- UV are not absorbed
- Very simple estimates of ionization state

X-ray shielding



But scattering in the wind can prevent shielding from the X-rays!

(Higginbottom et al. 2014)

Driving question

Can X-ray shielding work in realistic hydro-radiation-ionization simulations ?

Hydro-radiative-ionization simulations

We use PLUTO for the hydrodynamics part

$$\frac{\partial \rho}{\partial t} + \boldsymbol{\nabla} \cdot (\rho \mathbf{v}) = 0,$$

$$\frac{\partial (\rho \mathbf{v})}{\partial t} + \boldsymbol{\nabla} \cdot (\rho \mathbf{v}\mathbf{v} + p\mathbf{I}) = -\rho \boldsymbol{\nabla} \Phi + \rho \mathbf{g}_{\mathrm{rad}},$$

Isothermal equation of state

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Isothermal equation of state

And the Monte-Carlo radiative transfer and ionization code SIROCCO

(Matthews et al. 2025)

$$\mathcal{M}(\mathrm{t}) = \sum_{\mathrm{lines}} \Delta\nu_D \frac{J_\nu}{J} \frac{1 - \exp(-\eta_{u,l}\mathrm{t})}{\mathrm{t}}$$

$$\mathbf{g}_{\mathrm{rad}} = \sum_i^{N_{\hat{n}}} g_i = \sum_i^{N_{\hat{n}}} (1 + \mathcal{M}(\mathrm{t}_i)) \;\; \sigma_e \; \frac{\vec{F}_{\mathrm{UV},i}}{c}.$$

Sum over 450,000 lines!!!

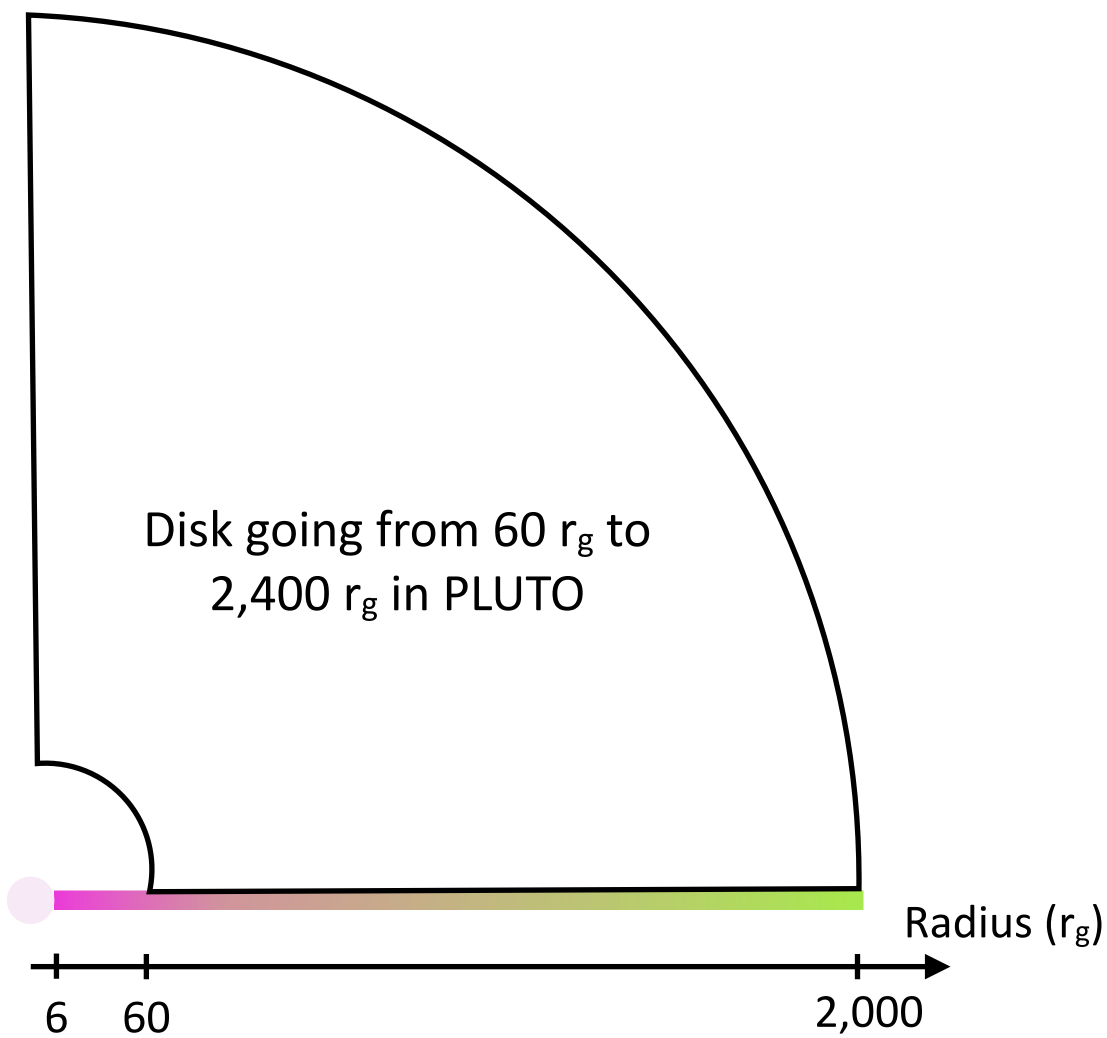
Numerical scheme

1. Run PLUTO for $\Delta t_{\rm HD}$
2. Give density, velocity and temperature to SIROCCO
3. Run SIROCCO for ionisation state and directional radiative fluxes in each cell
4. Compute $\mathbf{g}_{\rm rad}$
5. Do a new cycle!

Technique already validated in Higginbottom, **Scepi** et al. 2024

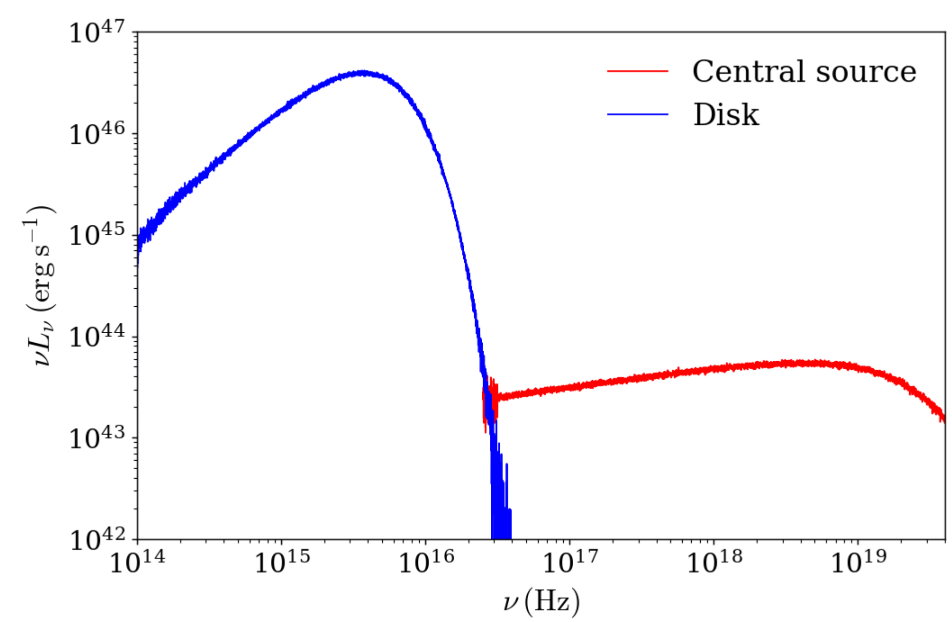
Set-up

2D simulation of 10^9 solar mass black hole accreting at 0.4 Eddington



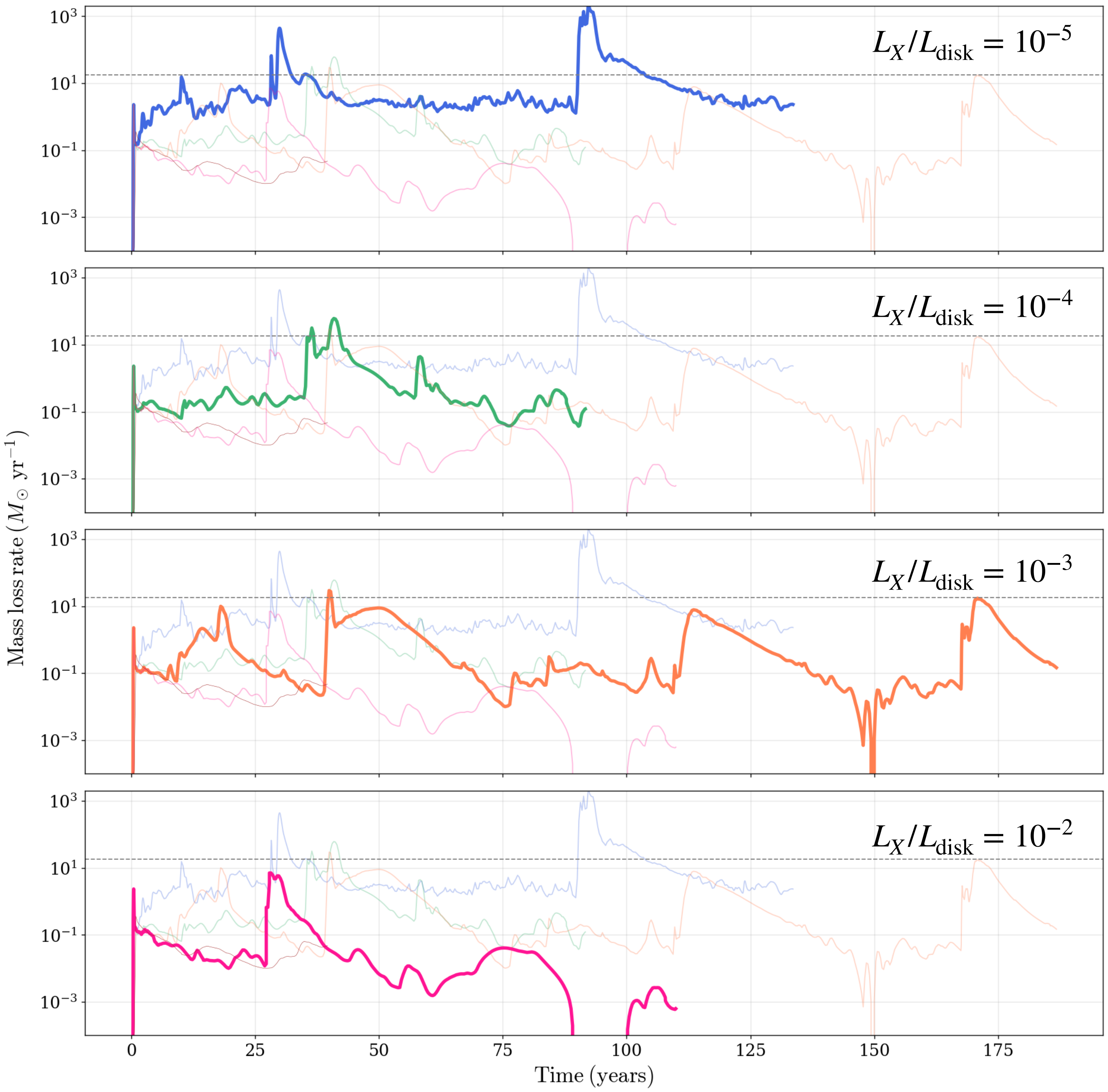
Radiation source in SIROCCO is :

- a disk going from 6 rg to 2,400 rg
- a central hard X-ray source



Mass-loss rates with different X-ray levels

Scepi et al. 2025, in prep.



Steady, powerful wind with

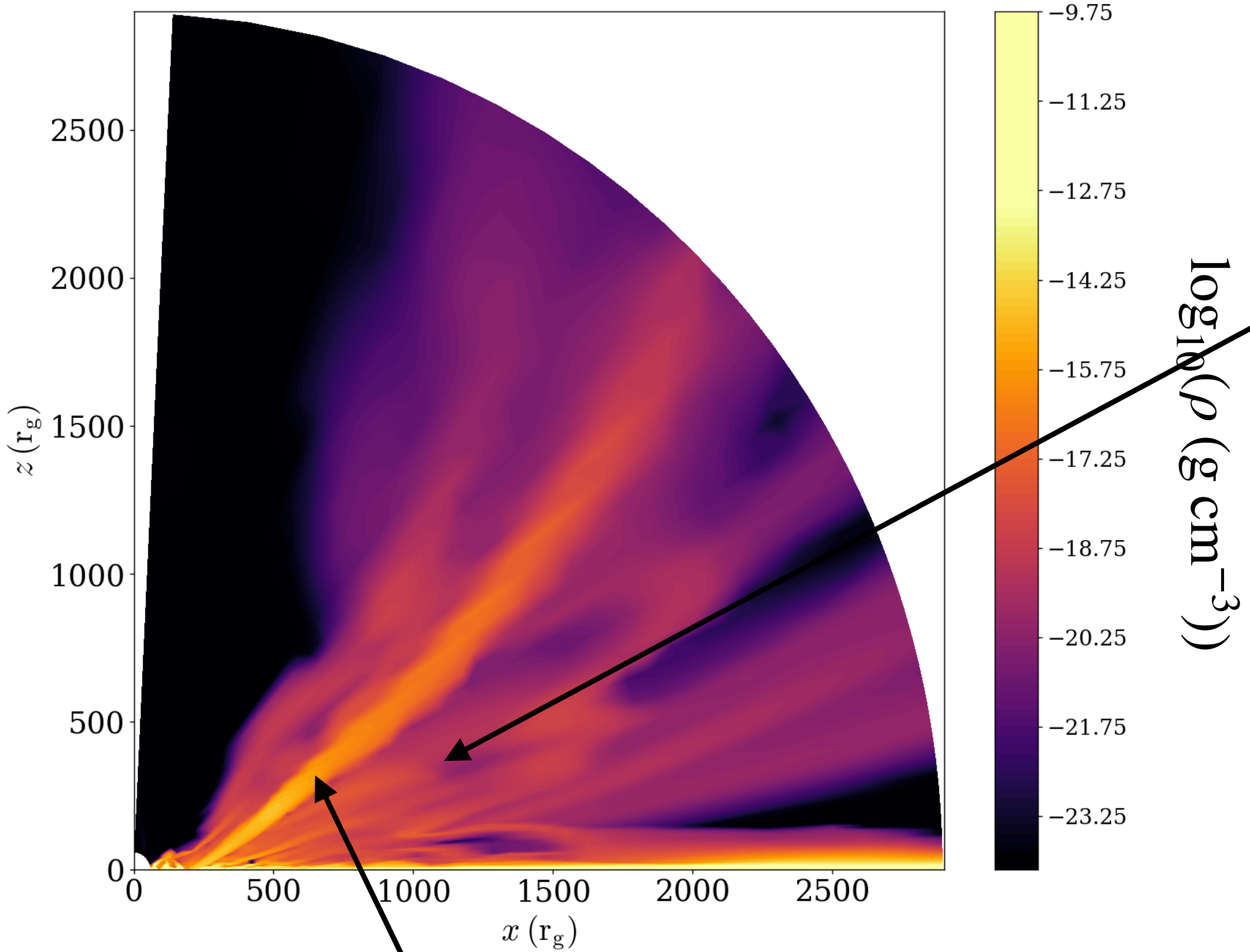
$\dot{M}_{\rm wind} \approx 25\,\%\,\dot{M}_{\rm acc}$

Transient wind with peaks where

$\dot{M}_{\rm wind} \approx 0.5\dot{M}_{\rm acc}$

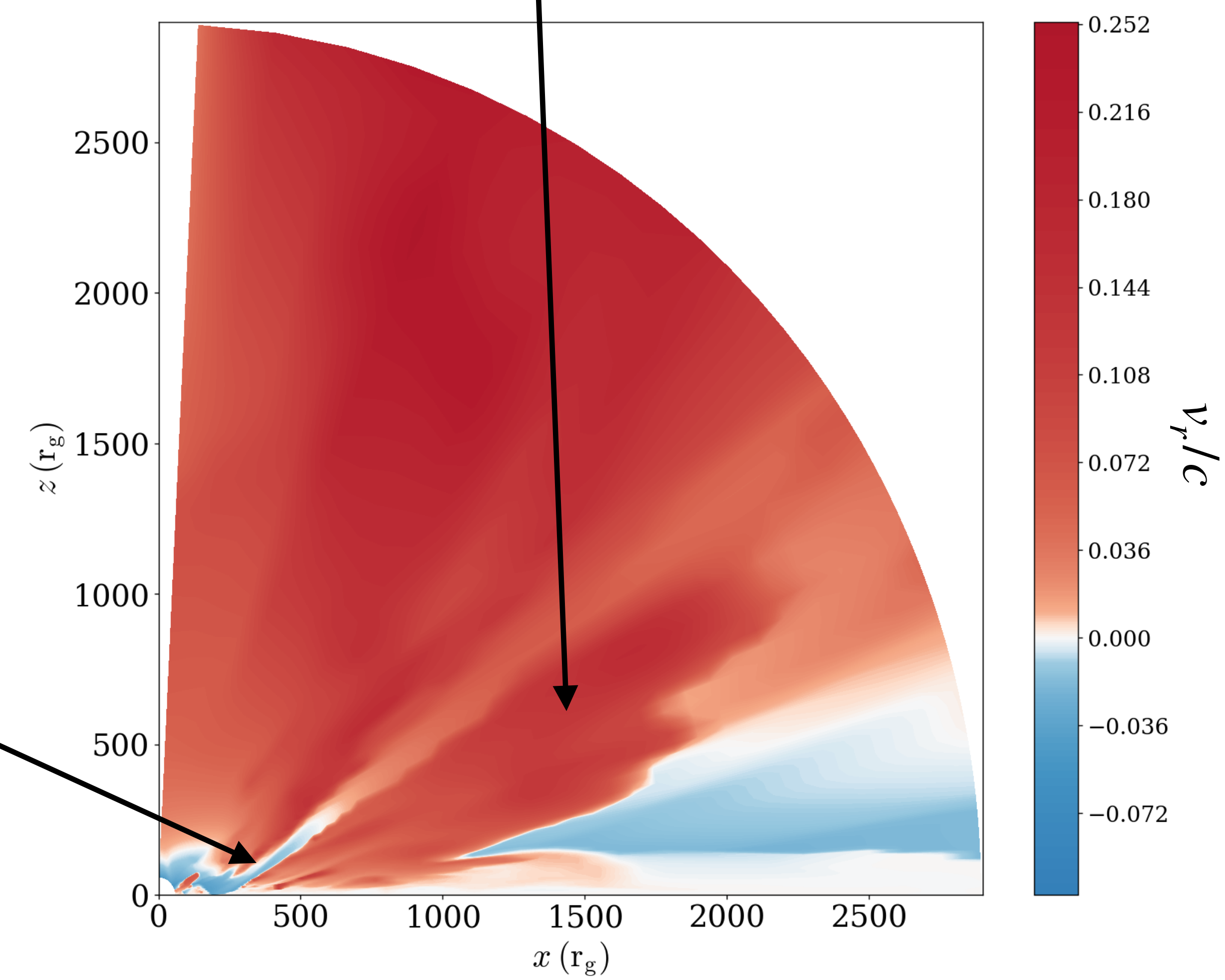
High X-ray simulation

Scepi et al. 2025, in prep.



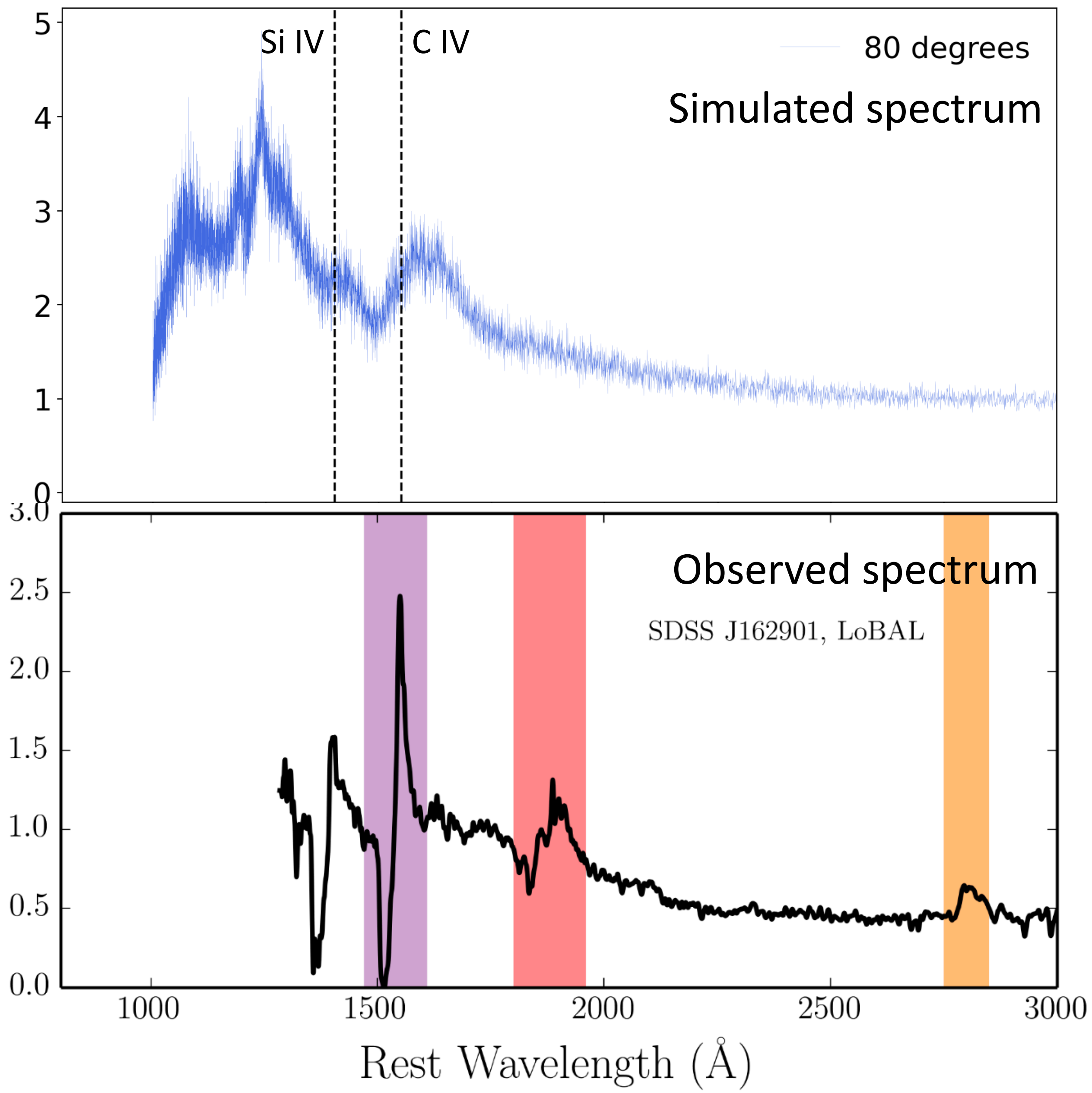
Shielded, fast wind

High density failed wind



Comparison to observations

Scepi et al. 2025, in prep.



Transient wind is enough to produce broad absorption lines !

Transient wind is actually quite in line with recent observations from XRISM on Ultra-Fast Outflows

Conclusion

Still a lot to explore with these new simulations
(different SEDs, different X-ray geometries, different BH masses)

X-ray shielding can work but very transiently !

However, our wind survive only to 1% Eddington, which is lower than for most AGN

Magnetic driving could help !